10.2 Studying uncertainties of internal doses due to variability in biokinetic models and dose coefficients by statistical modelling of parameter values

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Introduction

Radiological doses after incorporation of radionuclides are assessed by applying biokinetic and dosimetric models to measured activity levels in the body, excreta, air or food samples. Biokinetic models are used to mathematically describe the distribution of the radionuclides after their intake in the body. They provide information about the activity which is retained in different parts of the body over time and can be used to infer the amount of activity that entered the body and to calculate the number of decays in a source region. Dosimetric models describe the energy deposition (and thus the final dose) in organs (target regions) by the radiation emitted following the decay of radionuclides in different parts (source regions) of the body. The two core quantities in the assessment of the dose are the number of nuclear disintegrations occurring in the body (or the organs) and the energy transfer per decay (S-coefficient). The former values are calculated by integration of the retention function from biokinetic models, the latter are calculated using Monte Carlo Simulation of Radiation Transport [1] in computational phantoms representing human anatomy [2]. Uncertainties in internal dose assessments include contributions from both biokinetic and dosimetric models.

Uncertainties in biokinetic models

Biokinetic models proposed by ICRP [3, 4, 5, 6] use the compartmental formalism to describe the transfer between different parts (compartments) of the body or to excretion from it. The parameters of the models (transfer coefficients) provided by ICRP are intended to describe a reference biokinetic behavior. True parameter values of individuals will surely differ from the reference values. These deviations will lead to uncertainties in the model predictions and thus finally in the doses assessed. It is barely possible to estimate sets of parameters for individuals because most of the parameters are not directly identifiable by the measurements. Uncertainties arising from applying reference parameter values are studied by interpreting parameter values as statistical distributions with the reference value of the parameter as median or mean value of the distribution [7, 8]. The results of calculations with biokinetic models will then also become distributions which are interpreted as uncertainties of the model prediction. By varying all parameters an uncertainty analysis can be performed. This will provide information on the overall uncertainties associated with the application of the biokinetic model in the dose assessment.

Dosimetric models are based on anatomic human voxel models with segmented volumes for source regions and target organs [2]. Depending on geometric position, tissue densities and compositions the energy deposition after the decay of radionuclides (S-coefficient) differs for individuals from the calculated value. According to the literature [9] only a small contribution to the total uncertainty of the assessed dose can be assumed. The uncertainty of S-coefficients can be estimated by using the variability of organ masses for the specific absorbed fraction (SAF-values) for alpha emitters, which are mainly depositing their energy in the organ, in which they are emitted.

For the uncertainty analysis C++ software was developed. It consists of a biokinetic and a dosimetric part. The compartment models for the biokinetic behavior can mathematically be described by first order differential equations systems. The software solves the differential equations systems by eigenvalue decomposition in matrix notation [7, 8, 10]. The number of nuclear disintegrations in the source tissues can be calculated by integration of the biokinetic retention curve. For analyzing the biokinetic of all the decay chain of U-238, U-235 and Th-232, the recent biokinetic models [11] for the daughter nuclides were connected to their mothers with the decay rate. The transfer rates within the biokinetic models are by 14 orders of magnitude bigger than the decay rate of the long-lasting nuclides. Thus, the algorithms used for solving the system of equations becomes numerically instable. For avoiding this instability, the decay was detached from the biokinetic models and considered by modification of the model input.

The uncertainties in these values are studied using Monte Carlo simulations with transfer coefficient matrices, which were sampled from distributions of the individual transfer coefficients. In order to take into account correlations of the parameters, the sampling algorithm which generates the individual values has been adapted. Values of parameters which describe the same transfers (for example in the lung model) for different nuclides are sampled once and all correlated parameters are set to identical values in the complete decay chain.

Uncertainties in dosimetric models

The second part of the software tool calculates the energy transfer per decay (S-coefficient) out of the nuclear disintegrations occurring in the body (or the organs). The S coefficients are calculated with the specific absorbed fractions (SAF values) that were obtained from simulations with Monte Carlo Transport Codes of voxel models of the human body. The energy dependent SAF values and nuclear decay data (particle types, energies, emission probabilities) for the relevant radionuclides are provided by ICRP [1, 12]. The software reads the data and calculates the nuclide-dependent S coefficients for the different combinations of source and target organs. A special feature is the organ "Other Tissues", in which several organs of the biokinetic models are summarized. The element-dependent definition of the compartments, which form the source region "Other Tissues", must be considered.

Various factors were compiled which led to uncertainties in the dose coefficients from the literature. Overall, there are few studies in the literature on the uncertainty of the S-coefficients. It is assumed that the uncertainty in the nuclear decomposition data for most nuclides provides almost no contribution to the overall uncertainty of the dose coefficient. The uncertainty in the SAF-values for alpha decay can be estimated in a first approximation with the variability of the organ masses.

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